Standing Wave Probes for Micrometer-Scale Metrology

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In this project we are developing a low force, high-aspect-ratio, mechanical probe for the nondestructive characterization of manufactured components and assemblies. The key concept for the probe is the correlation between the dynamic response of an oscillating cantilever rod (probe) and the interaction of its tip with a surface (Fig. 1). The applications for this probe begin with surface location, but may encompass the characterization of the material properties of the surface, and perhaps branch into the modification of the surface. This project is a collaborative effort between LLNL, the University of North Carolina at Charlotte, the National Institute of Standards and Technology (NIST), and an industrial partner, InsituTec.

Project Goals

We will provide the scientific understanding of a low force, contact probe capable of being used on a number of machine tools and metrology platforms with a characterized uncertainty based on the fundamental understanding of the probing process. The exit strategy includes continued collaboration with the UNC-Charlotte team, rigorous calibration efforts with NIST, engaging a commercial source of probing instruments, and the probe's practical application at LLNL and its vendors for Inertial Confinement Fusion (ICF) and High Energy Density Physics (HEDP) target fabrication. A prototype instrument developed during this project will provide an excellent platform for continual reduction-to-practice efforts.

The final goal of this work is to enhance LLNL's precision metrology capabilities, which encompass key core technologies supporting NIF, Weapons Complex Integration, and nanofabrication.

Relevance to LLNL Mission

Currently, LLNL's ICF and HEDP targets comprise components with dimensions in the millimeter range, with micrometer-scale, high-aspect-ratio functional features, including fill-tube holes and counterbores, hohlraum starburst patterns, and step-joint geometry on hemispherical targets. In addition to the small-scale, complex geometry, these structures are often thin walled and manufactured out of delicate materials such as aerogels and/or metallic foams, which are susceptible to deformation and fracture during contact.

The near-term impact of this project is the expansion of LLNL's ability to accurately perform dimensional measurements of micrometer-scale features using a low force, high-aspect-ratio probe system.

FY2007 Accomplishments and Results

A prototype probe system has been built and is operational at LLNL including advanced electronics for increased sensitivity and upgraded mechanics for integration to any number of arbitrary motion control platforms, as shown in Fig. 2. The probe has been integrated into a profiling station with nanometer-

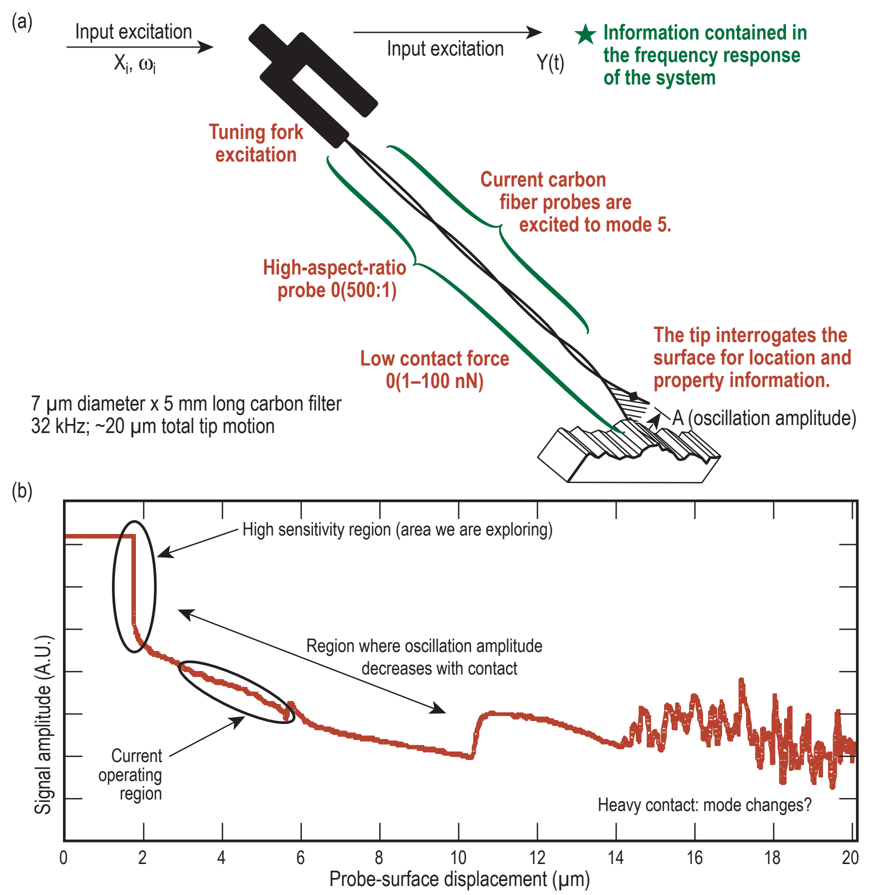

Figure 1. (a) Schematic description of probe system including tuning fork excitation and high-aspect-ratio rod. An input amplitude (X_i) at a frequency (ω_i) is applied to the tuning fork while the output amplitude (Y) is monitored as the probe comes into contact with the surface. (b) Output response of probe as it comes into contact with a surface.

level positioning capability and data acquisition. Experimental evaluation of probe performance is being quantified on this system. Probe sensitivity has been measured on three different materials including a metallic glass (Vitreloy 105), gold, and a hardened steel gage block.

A typical sensitivity experiment of the probe contacting a steel gage block is shown in Fig. 3. Results of these experiments indicate that probe sensitivity varies based on materials with similar surface finishes, as illustrated in Fig. 4.

A model of the probe dynamics including contact has been derived as a stand-alone model in Fortran. This model consists of an Euler-Bernoulli beam driven at one boundary by a tuning fork drive system; at the other end of the beam, we apply nonlinear contact conditions. Theoretical approximations of near surface (van der Waals, and electrostatic) and contact (impact, adhesion, and meniscus) forces have been developed and are applied to the numerical model.

Year one of the proposed effort comprises both the simulation of the probe's response when characterizing well-defined surfaces, and the acquisition of data using an experimental apparatus.

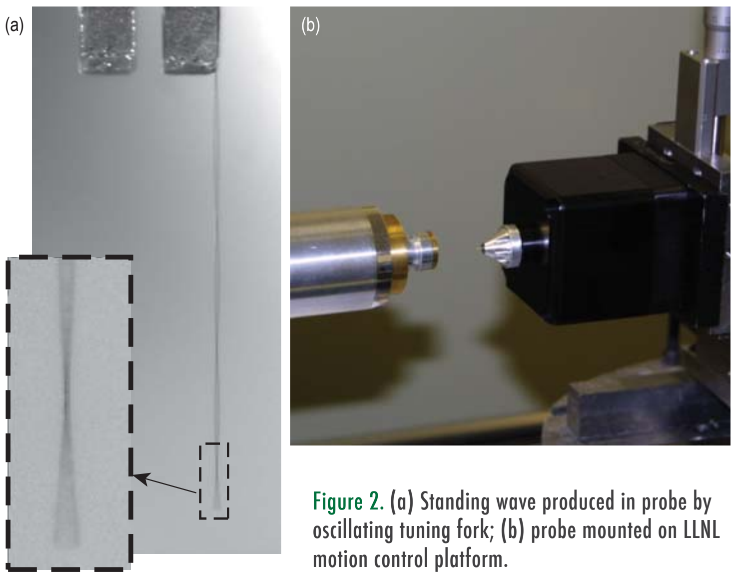

Figure 2. (a) Standing wave produced in probe by oscillating tuning fork; (b) probe mounted on LLNL motion control platform.

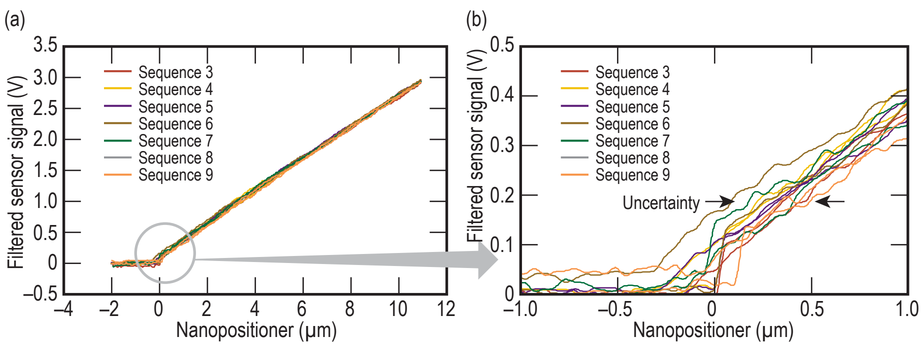

Figure 3. (a) Probe output contacting a steel gage block; (b) measurement uncertainty related to the variation in location of surface illustrated by the deviation between contact measurements. This deviation is a result of surface force interactions combined with environmental effects, such as thermal instability of the system and electronics.

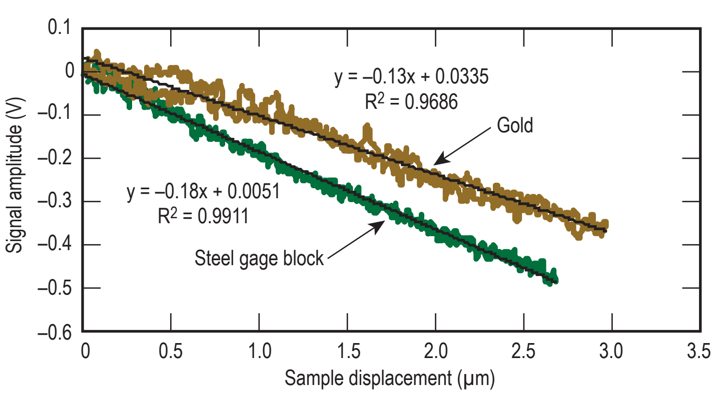

Figure 4. Sensitivity response as the probe comes into contact with a steel gage block and a gold sample of nominally the same surface finish.

Related References

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FY2008 Proposed Work

We plan on leveraging our understanding of the current probe system to develop a scaled version capable of operating on micrometer features with sub-micrometer-level sensitivity. We are also continuing analytical assessment of the probe system to incorporate actuation and sensitivity in multiple dimensions, and the feasibility of using the probe geometry for determination of material properties and/or surface modification.